THE HISTORICAL CONTINUITY OF SCIENCE

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Yet I doubt not thro' the ages one increasing purpose runs,
And the thoughts of men are widened with the process of the suns.
—Tennyson.

FROM the time that man first entered upon those labors which were to earn him that rich heritage of civilization which we own to-day two groups of objects presented themselves to his senses and his intelligence, each demanding, for sheer self-preservation, the closest study his intellect could furnish. The one group comprised his fellow-men, the other the sum total of objects and phenomena which comprised his non-human environment. From the study of the former group arose the juridical and political institutions of man, while from the study of the latter group arose his religions and his science. The motives urging him to these studies were the primeval instincts of self-preservation and curiosity, but unanticipated advantages accrued therefrom to the most successful students; from the first group of studies sprang the conquest, subjection and exploitation of less gifted or less fortunate members of his species, while from the second group of studies sprang the conquest and the interpretation of nature.

In one of his classical essays Huxley, for the purpose of expounding and illustrating the methods employed in his chosen field of investigation, has told us the story of Zadig, an illustrious philosopher and astrologer of ancient days, who by the minute observation and comparison of facts which were at first sight unrelated, was able to trace and restore to his imperial master the favorite horse and dog, the loss of which had constituted a national calamity the magnitude of which may well be imagined. But the illustration which was thus employed by Huxley to describe the methods of investigation employed in one particular field of scientific research might equally well have been employed to illustrate the discipline of thought in any other field of investigation. *Observation, comparison, deduction* and *trial* the success or failure of which inspires and directs further observations which form the starting-point of a new and wider cast of his net into the sea of the unknown, these are the successive steps in the discipline of thought which has slowly and inevitably led man from helpless dependency upon the caprice of nature to the present day when his words travel with the speed of light and his instruments pierce the depths of interstellar space.

The historical continuity of science and its origin in curiosity and the instinct of self-preservation seem in general to have been overlooked by scientific investigators and historians of science, and there are even certain authorities who, in complete forgetfulness of the fundamental canon of the scientific method enunciated by Newton, have urged that science can not be said to have begun until "laws of nature" had been formulated and the "causes" of phenomena ascertained.[1] But that is to invert the real evolution of scientific thought. As man's field of observation and comparison grew wider his deductions grew wider, until at length they became bounded only by the limits of the visible universe, but deductions are not knowledge, inferences are not science, they are merely implements which we wield for the further attainment of knowledge, the incitements to further research.

From the earliest dawn of history we find man formulating universal generalizations which he has deemed laws of nature. His intellect demanded knowledge which his feeble powers were not yet fitted to attain, so by a simple extension of the method of anticipating results which he employed in investigating the minor details of his accustomed environment, he launched out into the infinite and anticipated the totality of phenomena. These deductions formed the dogmatic bases of his religions, and since from their very nature they could not be subject to the control of trial to which his less exalted generalizations were required to submit, so trial became taboo and the acknowledgment of impotence was deferred by making a virtue of necessity and faith an attribute of piety.

But, our scientific historian may here exclaim, our laws of nature are true, and the fantastic imaginings of primeval man bore no necessary relation to fact. I would reply that all truth that is known to man is relative and that primitive religion bears exactly the same relation to fact, upon a narrower basis of knowledge, that our laws of nature bear to our wider knowledge of fact. They were the best generalizations that the profoundest and most inspired intellects of their age could form upon the basis of their then knowledge of the universe. Our generalizations represent no better efforts or manifest superiority of our intellect, they are the fruit of wider opportunities, but they do not therefore necessarily constitute the truth. There are certain curves well known to mathematicians, which, while they continuously approach a straight line, yet no matter how far we may trace them, short of tracing them to infinity itself, never actually attain the line. So with the knowledge of man; it is asymptotic to the Absolute, and continuously approaches but never attains the truth. Thus, while I do not deny that the law of the conservation of energy bears a closer relation to objective reality than the cryptic utterances of the Delphic oracle,

[1] For example, E. Ray Lankester, "Degeneration, a Chapter in Darwinism" in "The Advancement of Science," London, 1890.

yet the very universality of the generalization sets it apart from the actual knowledge, acquired of our senses, and places it in the realm of super-sensual belief.

Belief is not science, but the beliefs of man and the science of man are destined to develop as they have developed in the past, side by side, products of the same instinctive need, often apparently antagonistic because they approach the same infinitely distant goal from widely divergent angles. But as science asymptotically approaches the Infinite, so will religion approach science, until, when the intellect of man shall become commensurate to the totality of being, the two modes of interpretation will find at last their meeting-place in regions infinitely remote from the little knowledge of our day.

When we look back to the dawn of history and of written science we find man already advanced to a very comprehensive understanding and control of his environment. His conceptions were embryonic in comparison with ours, just as ours are but the germ from which will spring the ripe fruit of the knowledge of a thousand generations hence. Nevertheless in climbing the barrier which separated him from the Absolute, man at the dawn of history did not have to start from the level of utter ignorance and impotence. Far from it, for he had already attained a wide and inspiring outlook which only appears narrow to us to-day because we are vouchsafed an outlook so vastly more comprehensive that our larger perspective diminishes the vision of our ancestors to the dimension of a negligible proportion of the area which is now unfolded to our view. But in all the achievements of man "c'est le premier pas que coûte" and we, whose achievements will appear to our descendants so pitifully puny, can not afford not to pay our meed of profound respect to the accumulated product of the primitive facilities and unremitting toil of those who after all are removed from us in time by but an infinitesimal moiety of the eons which have been consumed in the accomplishment of our development.

Let us endeavor briefly to retrace a few of the most significant steps by which man attained that degree of knowledge and control of his environment which permitted the foundation of barbaric empires, the rise of which marks the dawn of recorded history.

The first essential step in this laborious ascent was the development of the tool. With his hands aided only by intelligence man could accomplish little more and in many directions of his endeavor less than many of the organisms which were directly or indirectly his competitors in the struggle for existence. Those concatenated reflexes which we term instincts were very much less elaborately developed in man than in many other inhabitants of his environment, a fact which was ultimately to his great advantage since his simple and primitive instincts were, by reason of their comparative simplicity, flexible and

adaptable to the vast variety of material and social environments in which man has by turns found himself situated. But in the early stages of his struggle for the mastery of nature the lack of elaborate instincts, such as those which enable the social hymenoptera to achieve such prodigies of skill and organization without the necessary exercise of any intelligence whatsoever—the lack of these placed man at a definite disadvantage. Physically not of the most powerful type and unassisted by elaborate instincts, he was compelled to supplement his deficiencies by the superiority of his intellect. Extension of his physical powers was the first prerequisite for supremacy, and this extension was afforded by the invention of the primitive tools, piercing, cutting, hacking, grinding and pounding instruments which multiplied the effectiveness of his physical powers by many thousand-fold.

The origin of the primitive pounding and grinding instruments is not far to seek, the first glimmerings of associative memory sufficed to provide us with these, as witness the fact that many animals and birds employ them. The cutting, piercing and hacking instruments demanded much more accurate observation, comparison, deduction and trial for their elaboration. In the beginning fortuitously encountered, the chance supply of ready-fashioned instruments would speedily be exhausted, and then it was that true inventiveness was called into play. First it must have been observed that certain types of stones yielded sharp edges while others did not, then that blows upon these stones produced cleavages and that some of these cleavages were sharp-edged and others were not, and finally by incessant trials sustained by inexhaustible patience and unflagging acuteness of observation, the correct type and direction of blow was ascertained which would yield a satisfactory instrument, a stone axe or an arrow-head, with an expenditure of time and labor which, although from our present point of view immense in proportion to the result attained, was nevertheless practicable and infinitely valuable in its outcome.

The first reliable hunting instrument must have been the spear and doubtless in many instances, as in the case of the living survival of neolithic man, the Australian aboriginal, the effectiveness of the spear was aided by throwing it at the object which was assailed. The customary killing of large animals yielded three very important results, first it increased the supply and variety of available food, secondly the skins (first assumed probably in imitation of the animals slain, in the performance of some obscure totemic rite) afforded clothing and increased enormously the possible geographic range of man, and thirdly the use of the sinew was discovered.

The utility of the sinew as a means of tying and binding may have been largely a fortuitous discovery, but what are we to say of the discovery of the bow? It should be observed that the bow is useless until

it is complete. The spear or arrow may be imperfect and yet admit of being impelled towards its object, but the means of impulsion embodied in the bow must have been completely developed and its purpose foreseen before its enormous utility could by any possibility be demonstrated. When we reflect upon the limited facilities and pitifully imperfect instruments of primitive man, upon his almost utter lack of experience of propelling instruments or indeed of any other kind of instruments, and of the conservatism imposed upon him by tribal ritual, we must I think admit that the discovery (or perhaps repeated rediscovery) of the bow is an unassailable proof of the existence among our primitive ancestors of men the creative vigor of whose intellect and capacity for taking infinite pains could not be surpassed by any of the investigators and inventors of our own epoch.

The power of man as a destructive agent was enormously enhanced by the discovery of the bow; no proportionate increase in destructive power was ever to occur again in his history until the day of the discovery of gunpowder. But power to destroy was not enough, the power to create was needed to supply its complement. Unchecked destruction implied ever increasing labors of the chase and automatically enforced a limitation to the human population of any given area, as happened, for example, in the areas inhabited by the North American Indian. But side by side with the rise of man's destructive power arose his constructive abilities, and it is in the means he chose and the success he achieved in his endeavor to provide a certain and predictable supply of animal food that we recognize some of the most striking evidence of the flexibility and adaptability of the intellectual weapon which he had begun to fashion for the conquest of nature.

The domestication of animals demanded minute observation of their habits in order to acquire that sympathy with their requirements which was an indispensable factor of success, and this knowledge acquired, the patience which was exerted in applying it must have been of an order which in our age of facile mediocre accomplishment is seldom displayed elsewhere than within the laboratory of the scientific investigator.

Returning again to a considerably earlier period in the history of primitive man, the discovery of the means of producing and the art of utilizing fire must have demanded abundant employment of observation, comparison, deduction and trial. I have elsewhere endeavored[2] to reconstruct in imagination the train of events which culminated in these discoveries. In the first instance the discovery of fire was probably fortuitous, but the number of factors, friction between the right types of surfaces, the presence of tinder of the requisite inflammability, the assistance of combustion by a current of air, while insufficiently

[2] "The Universe and the Mayonnaise and other Stories for Children." London and New York, John Lane, 1913.

large to preclude a not infrequent inadvertent assemblage of favorable conditions, was nevertheless sufficiently large to render their control at will a scientific problem which, to man at this stage of his development and facilities, must have been one of very formidable dimensions. We only know that it was surmounted, perhaps not once but many times. The laborious individual steps and the flashes of intellectual insight which led up to the conquest are necessarily lost to us forever.

If any of my readers is inclined to think that I place too high a valuation upon the intellectual exertions of primitive man, let him but try, as the author has done, with the powerful assistance of a modern jack-knife and all the inspiration afforded by familiar models, to make a practicable fire-stick or a bow and arrow which shall be something more than a toy. At the end of a few hours or days of endeavor he will have acquired a very enhanced respect for his ancestors.

The development of agriculture in its earliest stages called for foresight and prudence, but not, perhaps, for such extreme exertions of investigative ability as the inventions upon which I have hitherto been dwelling. Directly it passed the first stage of collecting edible plants in a convenient neighborhood, however, the development of agriculture demanded its share of observation, comparison, deduction and trial. The relationship of moisture to the growth of plants would be observed by a comparison of relative growth in different localities or patches of the same locality. In the neighborhood of rivers this would lead to irrigation and that in turn to the acquirement of some of the fundamental notions of hydromechanics. It would be observed, for example, that water would not flow up-hill except under pressure, that a "head" of water was capable of exerting pressure, that the water in two connected vessels tends to reach the same level in each, etc. The transition from a recognition of these principles to the formulation of the erroneous but exceedingly useful doctrine of the incompressibility of fluids required only the incorporation of mathematical conceptions which were destined to be the bye-product of the apparently unrelated enterprises of astronomy and architecture.

The development of architecture is generally traced from the tent of skins and the cabin of logs. Directly more ambitious edifices came to be attempted, however, a knowledge of the strength of materials and the relationship of stress and strain to structure became an imperative prerequisite of success, and by the now familiar process it was acquired. As the constructional details of a large edifice were too numerous to be simultaneously borne in mind, design became a necessary part of architecture, and geometry sprang from design.

The stars must necessarily have riveted the restless curiosity of man from a very early period in his development. Their utility as landmarks and as guides must speedily have impressed themselves upon

migratory people, and this would lead to a recognition of the periodicity of their apparent motions. These periodic changes, beginning with those of the sun and moon (leading to the conception of the day and month), laid the rude foundation of a calendar, the utility of which to the political leaders and organizers of mankind speedily became so evident that the calendar has from the dawn of history been regarded as an important preoccupation of government. From this sprang the early importance of the astrologer in the eyes of the state, more especially as the interpretive fertility of man's imagination had from an early period sought causes for the majestic harmonies of the skies, and these causes, so remote and so all-powerful, were well qualified to arouse the awe and veneration of mankind and an acknowledgment of man's impotence before the mighty forces of the universe and his respect for those whom he believed qualified to interpret the manifestations of this supernal power.

Under what circumstances and by what stages arose the primitive methods of isolating metals from their ores, of mixing them in the requisite proportions to form alloys possessed of properties differing from those of either constituent, and of fashioning the fragments thus obtained into instruments of war and agriculture we can not hope ever to definitely ascertain, but of this we may be absolutely certain, that the intellectual labors and expenditure of patience required to elaborate these crude beginnings of metallurgical science must have far exceeded the labor which, with all the wealth of accumulated experience and organized scientific knowledge we now possess, suffices to accomplish the elaboration of the numerous refinements and improvements of the metallurgical arts which are constantly issuing from our laboratories to-day.

During the ages which witnessed these remarkable developments of human control over nature, parallel developments had inevitably occurred in the juridical and political institutions of mankind. It may however be safely inferred that these developments rarely preceded but were rather the consequnce of the development of man's control over his environment. From their very nature it follows that these institutions are opportunist, and deal with things and men as they find them. For a politician in a pastoral society to frame and enact legislation adapted to an industrial population would be a folly which would speedily and inevitably precipitate disaster. Laws, whether laws of custom, tribal etiquette, or statutory enactment, were necessarily adapted to the people and environment on which they were imposed. Nothing can be clearer then, than that the formative forces which have created civilization have not resided in these institutions of mankind which have merely crystallized preexisting conditions into avowed and recognized forms. The creative forces have resided elsewhere and

their source, whether expressed as the material outcome of science or the spiritual outcome of religion, must be sought in the creative curiosity of man operating through the medium of a discipline of thought which has in every age been essentially identical with the now avowed and self-conscious discipline of thought which is most extensively and successfully employed by the scientific men whom we term to-day investigators and inventors. The ascent of man has therefore not been due, as historians would have us believe, to superhumanly wise statesmen, conquerors or administrators but solely to science and to the anticipations of its fruition which formed the basis of religions.

The increasing complexity of needs and industries now compelled cooperation, the improvement in the machinery of war, backed by the organization and discipline which sprang up in answer to the opportunities this machinery afforded, rendered extensive conquests feasible and the developments of agriculture rendered possible enormous accumulations of population in especially favorable localities. Hence at the dawn of recorded history we find the great river-beds and deltas of the east inhabited by dense populations loosely welded by conquest into inchoate empires.

The close association and interdependence of interests and information which these aggregations of humanity compelled furnished a tremendous stimulus to the development of knowledge and the control of the environment which they inhabited. Vanity inspired monumental architectural undertakings, necessity created intensive agriculture and vast irrigation enterprises, commercial or military necessity created ships out of the canoes and cockle-shells of primitive fishermen, and through the interchange of information and imitation and reapplication of successful devices a comprehensive rearrangement of preexisting knowledge took place, analogous to the modern development of the card index or vertical file from the bound register of inflexible dimensions, a rearrangement which without of necessity adding anything to knowledge, rendered existing knowledge very much more efficient.

During the growth of these great empires a people had arisen in the west, who were but little favored by natural environment but among whom the instinct of curiosity attained the intensity of a passion. Their very intelligence and energy, however, forbade their conquest and fusion into large conglomerates, while the absence of natural conditions favorable to the formation of dense aggregates of population subjected them to a wide dispersal and constant conflict with the forces of nature and with each other. Only the example afforded by contact with more favored and therefore more advanced civilizations was required however to bring about a speedy reversal of the relations of master and pupil in the curricula of civilization. The Greeks, whose gift of inspired curi-

osity has never been surpassed, perhaps indeed never equalled, most happily, by geographical proximity, furnished the connecting channel by which the accumulated knowledge of the east flowed to the receptive peoples of the west. But with their restless temperament and intellectual gifts the Greeks could not be mere passive recipients of facts. Everything that they received from Egypt, from Persia and from Asia Minor was transmitted to the west and to posterity marked with the indelible stamp of Greek genius. Isolated facts garnered from the east were multiplied by Greek investigators and welded into comprehensive generalizations.

For the first time the professional scientist who pursued science for its own sake appears in history. The multitude of isolated medical observations of the ancients were multiplied and interwoven into a system of medical practise by Hippocrates of Cos, and so intense was the enthusiasm and idealism with which he inspired his students that to this day the medical student enters upon the practise of his profession with the avowal upon his lips of the principles of medical practise which were enunciated by this great master. Geometry was applied to science by Archimedes and the fruits were the foundations of hydrostatics and mechanics. Great systematists like Democritus and Aristotle gathered together countless facts of nature and endeavored to weld them into a connected and interpretable whole.

With pupils such as these it is not surprising that the antique wisdom of the east had soon to turn to the west for inspiration. Greek architects were in request from the Ganges to the White Nile and Greek engineers directed the construction of those massive feats of engineering which were the stable foundations of the Roman Empire.

The fall of the Roman Empire, at first seeming the absolute destruction of civilization, simply resulted by steps which are too well known to require description here, in the dispersal of the seeds of knowledge over the continent of Europe. The practical knowledge of the Greeks was safe in the hands of countless artisans and engineers who transmitted it by word and example, enriched by experience and practise, to generations which succeeded them. The more abstract generalizations and inspired literature of the Greeks were kept alive by the sudden awakening into intellectual activity of a people who never before had evinced, and, their task accomplished, have never since displayed capability or desire of assimilating and constructing thought. Not only did the Arabs preserve for us the most perfect fruits of Greek thought, but they contrived a fresh and most significant importation from the east, algebra, the distinctive product of the contemplative rather than the kinetic intellect, a system of thought as truly expressive of the mentality of the peoples of India to whom we owe it as geometry was of the more rugged and virile mentality of the Greek.

Through the Feudal Ages, progressing slowly but inevitably towards the dawn of the renaissance, the seeds sown broadcast by the fallen empire germinated and brought forth fruit. By imperceptible degrees man's mastery over his environment became more complete, the slow sure grasp of science, never again to be relaxed, compelled nature to yield her secrets one by one. The augmenting industrialism and feats of engineering which heralded the renaissance were the fruit of the unregarded effort of countless individuals each of whom added a particle of knowledge to the accumulated store of science.

Practical knowledge was far advanced, but had fallen again into the disconnected condition in which the Greeks at an earlier period had received it from the east. Algebra was an independent branch of human thought, bearing no obvious relation to anything of practical import. The scientific discipline of thought, unconsciously employed by every artisan and engineer, had never been consciously formulated or avowed. The material was there, it awaited only the coming of the man who should weld it together and vitalize it with the inspiration of genius.

The man was found in René Descartes, who, as he tells us,[3] in the seclusion of "a room heated by a stove" wedded algebra to geometry, mathematics to science, and at the same time formulated in words and translated into acts one of the fundamental canons of scientific method, namely "*a plurality of suffrages is no guarantee of truth.*"

On that day science attained its majority and assumed self-consciously the burden of its appointed task. The last link was forged in the long chain of human endeavor which stretches from the insatiable aimless curiosity of our well-nigh Simian ancestors to the sublime conceptions of a Newton.

Of all strong things none is more wonderfully strong than man. He can cross the wintry sea, and year by year compels with his plough the unwearied strength of earth, the oldest of the immortal gods. He seizes for his prey the aery birds and teeming fishes, and with his wit has tamed the mountain-ranging beasts, the long-maned horses and the tireless bull. Language is his, and wind-swift thought and city-founding mind; and he has learnt to shelter him from cold and piercing rain; and has devices to meet every ill, but death alone. Even for desperate sickness he has a cure, and with his boundless skill he moves on, sometimes to evil, but then again to good.[4]

[4] Sophocles, "Antigone."

[3] "Discourse on Method," part II.